MFOA-ABC Hybrid Optimization Method for Dynamic Economic Dispatch of the 150 kV Sulselbar Electrical System

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Abstract*. This paper proposed a Modified Fruit Fly Optimization Algorithm-Artificial Bee Colony (MFOA-ABC) hybrid optimization method to solve the problem of dynamic economic dispatch (DED) of the 150 kV Sulselbar electrical systems by using two objective functions as tested parameters and considering power balanced, power limits of the generator, and generator ramp rate as constraints. Besides, the voltage profile, the L index voltage stability, and loading margin V-P on critical buses were evaluated. Results simulation of the MFOA-ABC optimization method were compared with other methods and it was obtained that the proposed method was better.*

Streszczenie. *W artykule zaproponowano hybrydową metodę optymalizacji zmodyfikowanego algorytmu optymalizacji muszki owocowej i sztucznej kolonii pszczół (MFOA-ABC) w celu rozwiązania problemu dynamicznej dystrybucji ekonomicznej (DED) systemów elektrycznych 150 kV Sulselbar przy użyciu dwóch funkcji obiektywnych jako testowanych parametrów i biorąc pod uwagę moc zrównoważony, limity mocy generatora i prędkość narastania generatora jako ograniczenia. Ponadto oceniono profil napięciowy, stabilność napięciową wskaźnika L i margines obciążenia V-P na krytycznych szynach. Porównano wyniki symulacji metody optymalizacji MFOA-ABC z innymi metodami i stwierdzono, że proponowana metoda jest lepsza.* (***Hybrydowa metoda optymalizacji MFOA-ABC dla dynamicznej ekonomicznej dystrybucji systemu elektrycznego 150 kV***).

Keywords: dynamic economic dispatch, L index voltage stability, loading margin V-P, MFOA-ABC hybrid method.
Słowa kluczowe: ekonomiczna dynamiczna dystrybucja, algorytmy genetyczne, metoda hybrydowa.

Introduction

In the development of electricity networks, the stability of the system will have a significant effect when all the isolated electricity networks or separates are interconnected [1]. The interconnection for large electric power systems needs to be done to maintain the distribution of electrical energy to load centers which can lighten the burden on the power station in the interconnection system [2]. While in [3], in the electricity system, it is very important to notice some elements related to reliability, quality, safety, stability, and continuity. Likewise in [4], the optimization of electric power systems is very important to increase quality system operating that can help manage and plan an electricity system. The priority of an engineer is how to design an electric power system that is optimal, efficient, and reliable with minimum operating and production costs [5]. As in [6], the main goal of electricity use is to provide high-quality and reliable power supplies to customers to fulfill the limit of operation and constraints on units of the power plant at the lowest cost. Besides, the challenge of an electrical engineer today and in the future is to optimize the generated power to the load centers with minimum operating costs [7]. Operating costs play an important role in the economic dispatching of the power generation systems. Moreover, factors affecting the generation of electric power at minimum operating costs are fuel costs and transmission losses [8].

Economic Dispatch (ED) in [9] states how to minimize objective functions and subject to the constraint where the amount of power generated must equal the received load where any transmission losses are negligible. The objective function is defined to minimize the total fuel cost of thermal plants with optimal generation power for the equality and inequality constraints [10]. The ED in [11] is about how to minimize the operating costs of power plants to get the optimal condition of power plants at a specified load. While in [12], the ED is about how to get the minimum total fuel costs of thermal power plants. ED aims to determine the optimal power output from the generating unit to meet the load demand by meeting the operating limits in a power distribution period where the line security limit is negligible [6]. However, in [13], the real power economic dispatch (ED) is about how to minimize the fuel cost of the whole system to meet the system load demand. While DED in [14] is about scheduling that can predict load changes for a certain time by coordinating the response capability of the generating unit. DED usually considers things such as emissions, generator ramp rate limits, renewable energy integration, and valve point effects. However, the researcher only took the power limits of the generator and generator ramp rate as constraints.

Several researchers have discussed optimization issues associated with ED such as particle swarm optimization (PSO) [15], enhanced quantum-behaved PSO [16], differential evolution [17], backtracking search [18], knee point-driven evolutionary [19], improved bacterial foraging [4], firefly [20], artificial bee colony [21], the Fuzzy Cardinal Method [22], enhanced moth-flame optimization [23], gravitational search [24], parallel and distributed computation [25], quadratic programming [26], MO-FOA [27], simulated annealing algorithm [28], hybrid PSO-TLBO optimization technique [29], new hybrid ICA-PSO approach [30], multi-objective harmony search algorithm [31], flower pollination algorithm [32], and chaotic Krill Herd algorithm [33].

In general, power plants in the world use thermal power plants, including in Indonesia. Electrical energy mostly is generated from thermal plants by using fossil fuels. Besides, fossil fuel availability in the world tends to decrease day by day, especially in Indonesia. Fuel depletion will increase the price of fuel and the cost of production for each generation unit. However, the increase in electrical devices used by the consumer will increase the fuel usage so that production costs become higher. Therefore, the optimization study about economic dispatch should be done to produce optimal generating power and the lowest operating cost of thermal power plants. This paper proposes a Modified Fruit Fly Optimization Algorithm-Artificial Bee Colony (MFOA-ABC) Hybrid optimization as a new method to solve the DED problem of 150 kV Sulselbar electrical system in Indonesia. Furthermore, to see the performance of the proposed MFOA-ABC Hybrid method, the simulation results were compared with other methods for the same electrical system. This paper is organized into three sections as follows: section one presents the research that is relevant to the research being investigated, section two describes the literature review, the objective functions and constraints used as well as an overview of the proposed (MFOA-ABC) Hybrid optimization method, and section three presents the simulation results obtained from a case study of the real electricity system of the 150 kV Suselbar thermal power plant and its discussion.

Problem Formulations

The problem formulations described in this paper are divided into two parts, namely the objective function and the constraints. The objective functions to be tested for minimization are fuel costs and transmission power losses. While, the constraints used are power balance, power limits of the generator, and generator ramp rate.

Fuel Costs

The economical operation of the thermal plant can be obtained by adjusting the input-output characteristics of the thermal plant. The input of the thermal plant is measured in Btu/h or $/h and the output of the thermal plant is measured in MW. The function of fuel cost at each generating unit is assumed to be known. The relationship between input and output characteristic of the H curve (MBtu/h) is obtained by multiplying the fuel (IDR/MBtu) to the function $f_i(P_i)$ in ($/h) [4,10,21]. The fuel cost variable of the generator as an objective function is a function of an economic perspective to minimize the fuel cost of each thermal power plant unit.

$$Min\ F = \sum_{i=1}^{N} F_i P_i = \sum_{i=1}^{N} (a_i P_i^2 + b_i P_i + c_i) \tag{1}$$

where: F is the total cost of generating fuel; F_iP_i is the fuel cost of each generator-i; P_i is the actual generator power of unit-i; a_i, b_i, c_i are fuel costs coefficient; and N is the total number of generators.

Transmission Power Losses

In large interconnection networks where the distance between the power plant and the load center is far, transmission losses are the main factors affecting the optimum scheduling of the plant [8]. Therefore, transmission power losses should be taken into account to achieve correctly economic dispatching. Transmission power losses are the power injection functions of the node, where the transmission power losses (P_{losses}) are expressed by using the B coefficient as follows: [3,4,34,35]

$$P_{losses} = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \tag{2}$$

where: i is the number of generators number, and j is the bus number in the system. B_{ij} is loss coefficients or B coefficients, B_{0i} is the loss coefficient vector for *ith* element, and B_{00} is the constant loss coefficient.

The Constraint Functions

The constraint functions referred to in this paper are constraints on the power limits of the generator, power balance, and generator ramp rate.

Power Limits of Generator

The input-output characteristic of the generating unit indicates that the output power is limited by the minimum and maximum capacity of the generating unit. The corresponding inequality constraint of the generating unit is

$$P_{i\,(min)} \leq P \leq P_{i\,(max)} \quad \text{for } i=1,2,\ldots,N \tag{3}$$

where: $P_{i(min)}$ is the minimum output power of each generator, P is the output power of each generator, and $P_{i(max)}$ is the maximum output power of each generator.

Power Balance

The equality constraint of power balance should be satisfied. The total generating power in the system must be equal to the total load demand and the total transmission power losses as shown in Equation (4).

$$\sum_{i=1}^{N} P_i = P_D + P_{losses} \tag{4}$$

where: P_i is the generating power of each generator, P_D is the total load demand, and P_{losses} is the total transmission power losses.

Generator Ramp Rate

A generator ramp rate is a generator that has the ability to respond to the rate of load changing over time [21]. It is used to prevent undesired outcomes owing to rapid dynamics alterations that exceed the ability of the generator to withstand them. The restriction is important if there is generator scheduling for a certain time so that it will affect the next generator unit limits as in Equation (5).

$$P_{min,i}^{t} = \max(P_{min,i}, P_i^{t-1} - DR_i), \text{ and} \tag{5}$$

$$P_{max,i}^{t} = \min(P_{max,i}, P_i^{t-1} + UR_i)$$

where: $P_{min,i}^{t}$ is the minimum limit at the time *t* of the *i*th generator, and $P_{max,i}^{t}$ is the maximum limit at the time *t* of the *i*th generator. However, $P_{min,i}$ represents the minimum limit of the *i*th generator and $P_{max,i}$ represents the maximum limit of the *i*th generator, and P_i^{t-1} is the *i*th generator output at the time *t-1*. DR_i is the descending rate value of the *i*th generator and UR_i is the ascending rate value of the *i*th generator.

Description of MFOA-ABC Hybrid Method

The MFOA-ABC hybrid optimization method is an optimization method proposed to solve the DED problem by combining two optimization methods between the FOA method *that is modified* and the ABC method. In this FOA optimization method, the distance traveled from fruit flies to get the best solution at this stage of the optimization process is extended in half from the previous distance to obtain the best minimum fitness value at the test limits [-1, 1]. The stages of the MFOA-ABC hybrid method in the initialization process were started with fruit fly and bee colony swarm for reading bus data, line data, power limits of the generator, generator ramp rates, and coefficients of generation fuel cost. The direction and distance traveled by the FOA flock and the bee colony were obtained from the position of the bus data parameters, line data, power limits of the generator, generator ramp rate, and fuel cost coefficient. Power flow using the Newton Raphson method is carried out to obtain the amount of voltage on each bus and the optimal power generation from each generator.

Furthermore, the process of calculating the fitness function is obtained from the direction and distance traveled by fruit flies and bee colonies as well as power flow to determine the minimum fitness value, namely the total fuel cost and the total transmission power loss.

The optimization process begins with the formation of a new solution from the bee colony swarm in the worker bee phase, all parameters are randomly modified to produce a mutant solution and randomly select a new fitness solution that is different from the previous one. If the value of this new resulting solution is outside its bounds, it will be shifted to the value of the bound. Then, an evaluation of the resulting new solution was carried out by calculating the new fitness solution. If the fitness value of the new solution is greater than the value of the previous mutant fitness, the value of the previous mutant fitness is the same as the fitness value of the new solution. Next, calculation of the probability value was carried out by calculating the fitness value divided by the maximum fitness value. In the spectator bee stage, all parameters are also randomly selected to produce a mutant solution and randomly select a new fitness solution that is different from the previous one in the recruited bee phase. If the value of the new solution generated is also outside the bounds, then the process will be shifted to the value of the bound. Then, an evaluation of the resulting new solution was carried out by calculating the new fitness solution. If the value of fitness of the new solution is greater than the value of fitness of the previous mutant in the recruited bee phase, the value of fitness of the previous mutant in the recruited bee phase is the same as the value of fitness of the new solution in the onlooker bee phase. Furthermore, the minimum fitness value for the new bee phase solution will be obtained. In the process of the bee scouting phase, the determination of the solution was done by selecting the trial counter value that exceeds the test limit value. If the trial value was greater than the limit value and the iteration had reached the maximum iteration, the minimum value of the fitness function would be obtained.

The final stage of this optimization process was to update bus data, line data, power limits of the generator, generator ramp rates, and fuel cost coefficients from fruit flies according to population size, the number of fitness functions, and test limits. Furthermore, updating of the direction and distance traveled by fruit flies was obtained from the position of bus data parameters, line data, power limits of the generator, generator ramp rate, and fuel cost coefficient. The process of recalculating the new fitness function was performed to determine the final fitness minimum value. If the final fitness function is less than the fitness function before optimization, the fitness value before optimization will be the same as the final fitness value.

The final stage of the MFOA-ABC hybrid method was to compare the values and positions of fruit fly and colony flocks obtained so far. If the fitness and position values of the resulting fruit flies are less or equal to the value of the bee colony, then the results taken are the result of the fruit fly swarm (MFOA) process, and vice versa. If the iteration has reached its maximum iteration, the minimum value of the fitness function will be displayed and the process ends.

Next, The procedure of FOA algorithm can be seen in [36] and ABC algorithm in [37]. The algorithm procedure of the MFOA-ABC hybrid optimization method can be described in the following steps:

1. Entry the parameters setting of MFOA and ABC
2. Determine the X-axis and Y-axis position of MFOA
3. Calculate distance and solution of MFOA
4. Calculate the objective function using Equation 6

(6) fitness(i)=ObjectFunct(sol(i,:))

5. Find the minimum fitness and its index
6. Get the X-axis and Y-axis minimum fitness
7. Determine the value limits of ABC
8. Calculate the objective function using Equation 7

(7) fitness=ObjectFunct(ObjVal)

9. Reset trial counters of ABC
10. Memorize the ABC best food (GlobalMin, and GlobalParams)
11. Enter into main iterative optimization, start iterative of employed bee phase
12. Calculate probabilities using Equation 8

(8) prob=(0.9*Fitness/max(Fitness))+0.1

13. Enter to iterative onlooker bee phase
14. Memorize the ABC best food source (GlobalMin, and GlobalParams)
15. Enter to scout bee phase
16. Set the food sources that the trial counter exceeds the limit value
17. Enter to MFOA iterative process
18. Repeat steps 2 to 5
19. If a new value is smaller *than* the best value, update the best value
20. Get the Smellbest and best of MFOA
21. If update the best value of MFOA (Smellbest) smaller or equal *to* the best food source of ABC (GlobalMin) or vice versa and *the* best index of FOA smaller or equal GlobalParams index of ABC or vice versa, then
22. The value of Smellbest is equal to GlobalMin or vice versa, and the best index is equal to GlobalParams index or vice versa.

Simulation Results and Discussion

1. Testing of 150 kV Sulselbar Electrical System

Sulselbar 150 kV existing electrical system in Indonesia is an electrical system consisting of 29 buses, 36 transmission lines, and 9 generators but only 7 generators were working, with a total load of 565,150 MW. The test data related to this system when peak load occurred, as in [28]. In this paper, the test was carried out only on 7 active bus generators, namely the Balusu bus, Tello bus, Punagaya bus, Tallasa bus, Pare-Pare bus, Palopo bus, and Sengkang bus, while the other 2 buses were not operated, namely Sungguminasa bus and Bakaru bus. Single line diagram of the electrical system can be seen in Fig.1. The fuel cost function is shown in Table 1, while the power limits of the generator and the generator ramp rate are shown in Table 2.

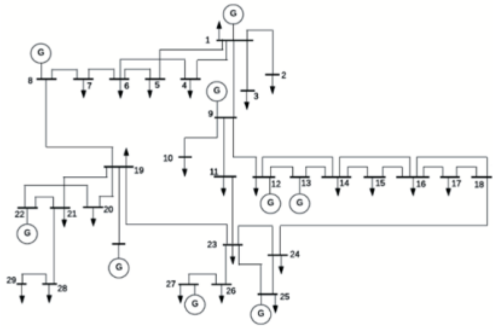

Fig.1. Single line diagram of the 150 kV Sulselbar electrical system

where: bus 1=Tello, bus 8=Balusu, bus 9=Sungguminasa, bus 12=Tallasa, bus 13=Punagaya, bus 19=Pare-Pare, bus 22=Bakaru, bus 25=Sengkang, bus 27=Palopo.

Table1. Function of fuel cost of the 150 kV Sulselbar electrical system

Unit	Function of Fuel Cost (IDR/hour)
1	$1.3736e-9+2240.9P_1+7.1332e-8(P_1)^2$
2	$-2.4144e-11+427.4\,P_2-1.1182e-8(P_2)^2$
3	$-3.6365e-11+1917.8P_3-4.5984e-8(P_3)^2$
4	$6.346e-12+432.75P_4+1.9212e-7(P_4)^2$
5	$-2.5302e-11+1908.44P_5+1.8497e-8(P_5)^2$
6	$-4.7539e-12+427.78P_6-1.0608e-7(P_6)^2$
7	$1.587e-10+2634.3P_7+1.3227e-8(P_7)^2$

Table 2. Power limits of the generator and generator ramp rate of the 150 kV Sulselbar electrical system

Unit	P_{min} (MW)	P_{max} (MW)	UR (MW/h)	DR (MW/h)
1	2	8	480	480
2	9.68	38.73	180	180
3	5	8	480	480
4	55.59	222.35	180	180
5	15	60	480	480
6	54.88	219.5	600	600
7	1.25	5	480	480

The test was carried out in two stages to see the effectiveness and performance of the proposed MFOA-ABC hybrid method. The first test was carried out for the generator limits as constraints and the second test was carried out for the generator limits and the generator ramp rates as constraints. The test results using the MFOA-ABC hybrid optimization method for the generator power limits, and the power balance as a constraint are shown in Table 3 and the convergence curve of the fuel cost is shown in Figure 2 with the required computation time of 584.695 seconds.

Table 3. The optimization results using MFOA-ABC hybrid method with the power limits of the generator as a constraint

Bus name	Generating power (MW)	Generation fuel costs (IDR/hour)
Tello	8	17927200.000
Balusu	22.930	9800282.000
Tallasa	8	15342400.000
Punagaya	238.1638	103065402.5866
Pare-Pare	51.1	97521284.000
Sengkang	242.67	103809372.594
Palopo	5	13171500.000
Total	575.8638	360637441.1804
Total transmission power losses (MW)	10.714	

Table 3 shows the value of the optimization results of 150 kV Sulselbar electrical system test with the power limits of the generator, and power balance as constraints using the MFOA-ABC hybrid method for transmission power losses of 10,714 MW and the generating fuel costs of 360637441.1804 (IDR/hour).

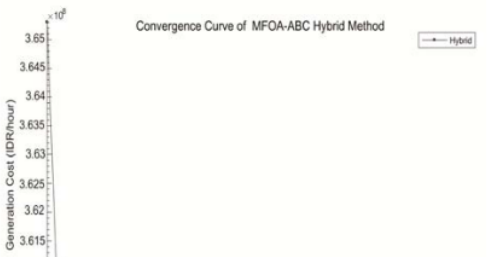

Fig.2. Convergence curve of the 150 kV Sulselbar electrical system with power limits of the generator and power balance as constraints

The test results using the MFOA-ABC hybrid optimization method for the power limits of the generator, power balance, and generator ramp rate as constraints are shown in Table 4 and the fuel cost convergence curve is shown in Figure 3 with the required computation time of 604.583 seconds.

Table 4. The optimization results using MFOA-ABC hybrid method with power limits of the generator, and generator ramp rate as constraints

Bus name	Generating power (MW)	Generation fuel costs (IDR/hour)
Tello	8	17927200.000
Balusu	22.930	9800282.000
Tallasa	8	15342400.000
Punagaya	244.031	105604523.666
Pare-Pare	51.1	97521284.000
Sengkang	242.67	103809372.594
Palopo	5	13171500.000
Total	581.731	363176562.260
Total transmission power losses (MW)	16.583	

Table 4 shows the value of the optimization results using the MFOA-ABC hybrid method with power limits of the generator, power balance, and generator ramp rate as the constraints for transmission power losses of 16,583 MW and the generation fuel cost was 363176562,260 (IDR/hour).

Next, the comparison of the optimization results with the power limits of the generator, and the power balance as the constraint using the MFOA-ABC hybrid optimization method with other methods being the comparison for the same electrical system is shown in Table 5.

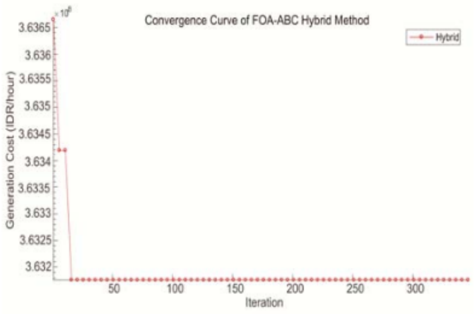

Fig.3. Convergence curve of the 150 kV Sulselbar electrical system with the power limits of the generator, power balance, and the generator ramp rate as constraints

Table 5. Comparison results using MFOA-ABC hybrid method with other methods using generator power limit as the constraint

Objective function	Method				
	MFOA-ABC Hybrid	FOA-ABC Hybrid [2]	FOA	ABC [14]	Lagrange [38]
Total transmission power losses (MW)	10.714	16.583	20.303	20.844	23.471
Total generation fuel cost, million (IDR/hour)	360.637	363.176	364.787	365.010	366.158

Table 5 shows the comparison of the optimization results of the 150 kV Sulselbar electrical system with generator power limit, and that power balance as constraints using the MFOA-ABC hybrid optimization method had a smaller value than the four optimization methods being compared, namely the FOA-ABC hybrid method, the FOA method, the ABC method, and the Lagrange method for the two objective functions tested, namely the total generation fuel cost and transmission power losses with the generator power limit as the constraint. Thus, the difference in transmission power losses using the MFOA-ABC hybrid method with the FOA-ABC hybrid method was 5.869 MW or there was a decrease in transmission power losses by 35.39 percent. The difference in transmission power losses using the MFOA-ABC hybrid method with the FOA method was 9,589 MW or there was a decrease in transmission power losses by 47.23 percent. The difference in transmission power losses using the MFOA-ABC hybrid method with the ABC method was 10.13 MW or there was a decrease in transmission power losses by 48.59 percent. Meanwhile, the different transmission power losses using the MFOA-ABC hybrid method with the Lagrange method was 12,757 MW or there was a decrease in transmission power losses by 54.35 percent.

While the difference in generation fuel costs using the MFOA-ABC hybrid method with the FOA-ABC hybrid method was 2.539 million (IDR/hour) or a decrease in fuel costs by 0.69 percent. The difference in generation fuel costs using the MFOA-ABC hybrid method with the FOA method was 4.15 million (IDR/hour) or a decrease in the use of fuel costs by 1.14 percent. The difference in generation fuel costs using the MFOA-ABC hybrid method with the ABC method was 4.373 million (IDR/hour) or a decrease in the use of fuel costs by 1.19 percent. Meanwhile, the difference in generation fuel costs using the MFOA-ABC hybrid method with the Lagrange method was 5,521 million (IDR/hour), or a decrease in the use of fuel costs by 1.51 percent.

Meanwhile, the comparison of the optimization results using the MFOA-ABC hybrid method with other methods for the power limits of the generator and the generator ramp rate as a constraint is shown in Table 6.

Table 6. Comparison results using MFOA-ABC hybrid method with the other methods with power limits of the generator and generator ramp rate as the constraints

Objective function	Method		
	MFOA-ABC Hybrid	FOA	ABC [14]
Total transmission power losses (MW)	16.583	20.222	20.844
Total generation fuel cost, million (IDR/hour)	363.177	364.752	364.990

Table 6 shows the comparison of optimization results of 150 kV Sulselbar electrical system using the MFOA-ABC hybrid method with the FOA method and the ABC method as a smaller comparison method for power limits of the generator, power balance, and generator ramp rate as the constraints. The difference in total transmission power losses of the MFOA-ABC hybrid method with the FOA method was 3,639 MW or there was a decrease in transmission power losses by 17.99 percent. Meanwhile, the difference between the total transmission power losses of the MFOA-ABC hybrid method with the ABC method was 4,261 MW or there was a decrease in transmission power losses by 20.44 percent.

The difference in generating fuel costs using the MFOA-ABC hybrid method with the FOA method was 1.57531 million (IDR/hour) or there was a decrease in the use of generating fuel costs by 0.43 percent. Meanwhile, the difference in generating fuel costs using the MFOA-ABC hybrid method with the ABC method was 1.813716 million (IDR/hour) or there was a decrease in the use of generator fuel costs by 0.49

2. L Index Voltage Stability of 150 kV Sulselbar Electrical System

In the 150 kV Sulselbar electrical system, an evaluation of the voltage profile on each bus was carried out using the L index voltage stability. Buses that had the largest L index value were buses that were considered weak or quite critical in the system.

The voltage stability with the L index approach using the MFOA-ABC hybrid method is shown in Table 7 and the graph of the L index value and the voltage value is shown in Figure 4.

Table 7. The L index value of the voltage stability of the 150 kV Sulselbar real system using MFOA-ABC hybrid method

Bus number	L Index	Voltage (pu)
2	0.0017	0.9464
3	0.0148	0.9342
4	0.0027	0.9477
5	0.0057	0.9463
6	0.0042	0.9484
7	0.0019	0.9580
9	0.0022	0.9517
10	0.0057	0.9484
11	0.0061	0.9816
14	0.0045	0.9866
15	0.0085	0.9852
16	0.0120	0.9846
17	0.0141	0.9848
18	0.0137	0.9871
20	0.0031	0.9775
21	0.0045	0.9774
22	0.0040	0.9776
23	0.0033	0.9916
24	0.0057	1.0019
26	0.0023	0.9421
28	0.0112	0.9723
29	0.0133	0.9706

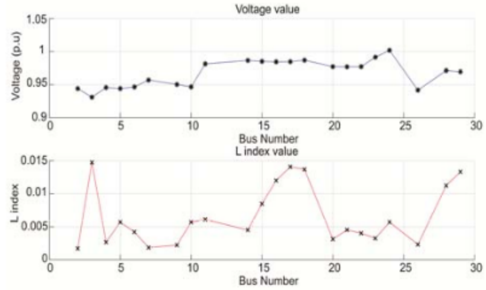

Fig.4. The L index value and voltage of the 150 kV Sulselbar real system using the Hybrid MFOA-ABC method

Table 8. Voltage profile comparison using MFOA-ABC hybrid method with other methods by generator power limit as a constraint

Load bus number	Voltage (p.u)			
	Method			
	MFOA-ABC Hybrid	FOA	ABC	Lagrange
2	0.9464	0.9435	0.9434	0.9428
3	0.9342	0.9078	0.9067	0.9012
4	0.9477	0.9432	0.9430	0.9421
5	0.9463	0.9367	0.9363	0.9343
6	0.9484	0.9412	0.9409	0.9394
7	0.9580	0.9545	0.9544	0.9536
9	0.9517	0.9463	0.9460	0.9446
10	0.9484	0.9369	0.9364	0.9337
11	0.9816	0.9692	0.9685	0.9655
14	0.9866	0.9797	0.9794	0.9778
15	0.9852	0.9717	0.9710	0.9681
16	0.9846	0.9654	0.9646	0.9604
17	0.9848	0.9625	0.9615	0.9567
18	0.9871	0.9647	0.9637	0.9588
20	0.9775	0.9729	0.9727	0.9717
21	0.9774	0.9719	0.9717	0.9705
22	0.9776	0.9728	0.9726	0.9715
23	0.9916	0.9846	0.9842	0.9824
24	1.0019	0.9917	0.9912	0.9888
26	0.9421	0.9405	0.9404	0.9398
28	0.9723	0.9569	0.9562	0.9530
29	0.9706	0.9521	0.9513	0.9474

Table 7 and Figure 4 show that the largest L index value and the smallest voltage using the MFOA-ABC hybrid method was on bus 3 (Panakkukang bus), which was 0.0148 with a voltage value of 0.9342 p.u. Meanwhile, the largest voltage value was on bus 24 (Soppeng bus), which was 1,0019 p.u with an L index value of 0.0057. The biggest L index value, which was on bus 3 (Panakkukang bus), was a bus that was considered quite critical in the 150 kV Sulselbar electrical system.

Comparison voltage profile using the MFOA-ABC hybrid method with the other methods by generator power and power balance as constraints is shown in Table 8 and the graph of the comparison is shown in Fig.5.

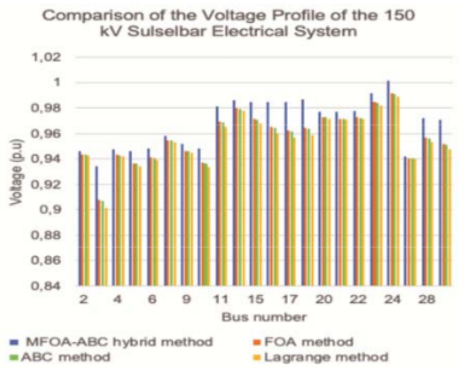

Fig.5. Comparison graph of the voltage profile by using MFOA-ABC hybrid method with other methods

Table 8 and Figure 5 show that the voltage stability in the 150 kV Sulselbar real system test using the proposed MFOA-ABC hybrid method was better than the voltage stability in the FOA method, the ABC method, and the Lagrange method with the power limits of the generator and power balance as constraints. Voltage values below 0.95 p.u using the MFOA-ABC hybrid method were on bus 2 (Tello bus), bus 3 (Panakkukang bus), bus 4 (Kima bus), bus 5 (Bosowa bus), bus 6 (Pangkep bus), bus 10 (Tanjung Bunga bus), and bus 26 (Makale bus), which showed the voltage instability occurring on these buses. Voltage values below 0.95 p.u using the FOA method were on bus 2 (Tello bus), bus 3 (Panakkukang bus), bus 4 (Kima bus), bus 5 (Bosowa bus), bus 6 (Pangkep bus), bus 9 (Sungguminasa bus), bus 10 (Tanjung Bunga bus), and bus 26 (Makale bus), which indicated that voltage instability occured on these buses. Furthermore, the voltage value below 0.95 p.u using the ABC method was on bus 2 (Tello bus), bus 3 (Panakkukang bus), bus 4 (Kima bus), bus 5 (Bosowa bus), bus 6 (Pangkep bus), bus 9 (Sungguminasa bus), bus 10 (Tanjung Bunga bus), and bus 26 (Makale bus), which indicated that voltage instability occurred on these buses. Meanwhile, the voltage value below 0.95 p.u using the Lagrange method was on bus 2 (Tello bus), bus 3 (Panakkukang bus), bus 4 (Kima bus), bus 5 (Bosowa bus), bus 6 (Pangkep bus), bus 9 (Sungguminasa bus), bus 10 (Tanjung Bunga bus), bus 26 (Makale bus), and bus 29 (Mamuju bus) which indicated that voltage instability occurred on these buses. Meanwhile, the smallest voltage value was on bus 3 (Panakkukang bus) by using the MFOA-ABC hybrid method, the FOA method, the ABC method, and the Lagrange method, which were 0.9342 p.u, 0.9078 p.u, 0.9067 p.u, 0.9012 p.u and they were considered quite critical buses in the system.

3. Loading Margin (V-P) of the 150 kV Sulselbar System

The V-P curve by using the MFOA-ABC hybrid method with power limits of the generator and power balance as a constraint was carried out on buses that were considered quite critical, namely bus 3 (Panakkukang bus) of the 150 kV Sulselbar electrical system with a voltage value of 0.9342 p.u.

The loading on bus 3 was carried out to show the V-P loading margin curve, bus 3 is a bus that is considered quite critical with loading of 289 MW where the L index values and voltage are shown in Table 9 and the V-P curve graph is shown in Figure 6. Next, the optimization results of the generating fuel cost and transmission power losses by using two objective functions and the power limits of the generator as a constraint with loading of 289 MW are shown in Table 10 and convergence curve as shown in Figure 7 with the required computation time of 90619.467 seconds.

Table 9. The L index value of the voltage stability using the MFOA-ABC hybrid method with loading on bus 3 of 289 MW

Bus number	L Index	Voltage (pu)
2	0.0012	0.9469
3	0.0491	0.9037
4	0.0019	0.9484
5	0.0040	0.9478
6	0.0030	0.9495
7	0.0013	0.9584
9	0.0020	0.9519
10	0.0044	0.9496
11	0.0043	0.9831
14	0.0027	0.9880
15	0.0055	0.9877
16	0.0082	0.9878
17	0.0099	0.9882
18	0.0092	0.9907
20	0.0022	0.9783
21	0.0031	0.9782
22	0.0028	0.9783
23	0.0023	0.9924
24	0.0042	1.0032
26	0.0021	0.9422
28	0.0077	0.9747
29	0.0092	0.9735

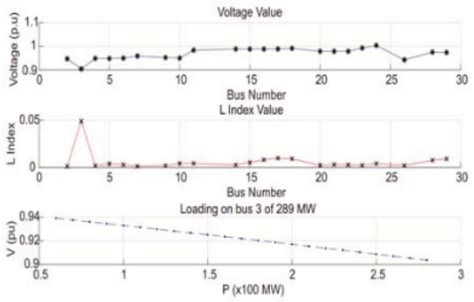

Fig.6. Graph of the V-P curve by using the MFOA-ABC hybrid optimization method with loading on bus 3 of 289 MW

Table 9 and Figure 6 show that when the loading on bus 3 (Panakkukang bus) reached a loading power of 289 MW, the value of the L index voltage stability on bus 3 was 0.0491 (the largest L index value) with the voltage on the bus 3 of 0.9037 p.u (voltage value smallest). By looking at the voltage value obtained on bus 3, it can be seen that the voltage condition on bus 3 was already below the voltage stability limit allowed in the electric power system but was still within the voltage limit which is not considered critical enough. The loading limit was on bus 3 when the loading reached 289 MW where the voltage will collapse.

Table 10. The optimization results using MFOA-ABC hybrid method with the generator power limit as a constraint when loading on bus 3 of 289 MW

Bus name	Generating power (MW)	Generation fuel costs (IDR/hour)
Tello	8	17927200.000
Balusu	22.930	9800282.000
Tallasa	8	15342400.000
Punagaya	466.816	202014555.193
Pare-Pare	51.1	97521284.000
Sengkang	242.67	103809372.594
Palopo	5	13171500.000
Total	804.516	459586593.787
Total transmission power losses (MW)	26.79	

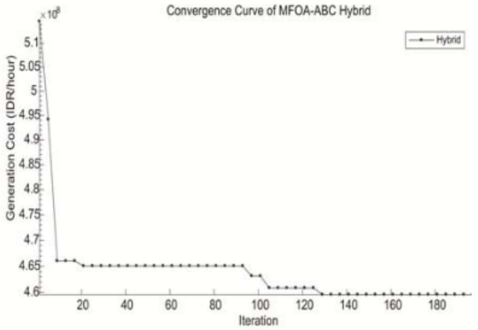

Fig.7. The convergence curve of generating fuel costs by using MFOA-ABC hybrid method when loading on bus 3 of 289 MW

Table 11. Comparison of the voltage profile on bus 3 using MFOA-ABC hybrid method, and other methods when loading 289 MW

Bus number	Value (p.u)	Method		
		MFOA-ABC Hybrid	FOA	ABC
2	Voltage	0.9469	0.9435	0.9434
3		**0.9037**	**0.6915**	**0.6772**
4		0.9484	0.9425	0.9422
5		0.9478	0.9356	0.9351
6		0.9495	0.9399	0.9394
7		0.9584	0.9531	0.9528
9		0.9519	0.9341	0.9327
10		0.9496	0.9247	0.9230
11		0.9831	0.9641	0.9630
14		0.9880	0.9782	0.9776
15		0.9877	0.9694	0.9683
16		0.9878	0.9615	0.9601
17		0.9882	0.9574	0.9557
18		0.9907	0.9619	0.9604
20		0.9783	0.9729	0.9727
21		0.9782	0.9720	0.9717
22		0.9783	0.9728	0.9726
23		0.9924	0.9822	0.9816
24		**1.0032**	**0.9892**	**0.9884**
26		0.9422	0.9398	0.9397
28		0.9747	0.9569	0.9562
29		0.9735	0.9522	0.9513

Table 10 and Figure 7 show the optimization results of 150 kV Sulselbar electrical system test using the MFOA-ABC hybrid method when loading on bus 3 of 289 MW, the total of generating fuel cost was 459586593,787 (IDR/hour) and transmission power losses of 26,790 MW.

Next, a comparison of the voltage profile when the loading was on bus 3 of 289 MW using the Hybrid MFOA-ABC method, the FOA method, and the ABC method is shown in Table 11 and the graph of the voltage profile is shown in Figure 8. Meanwhile, the comparison of the total use of generating fuel costs and transmission power losses of the 150 kV Sulselbar electrical system are shown in Table 12 and the comparative graph of generating fuel costs and transmission power losses is shown in Figure 9.

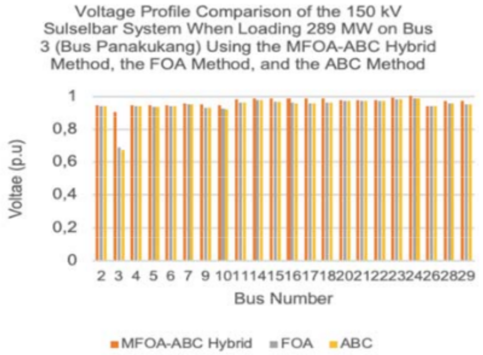

Fig.8. Graph of the voltage profile when loading on bus 3 of 289 MW using MFOA-ABC hybrid method, FOA method, and ABC method

Table 11 and Figure 8 show that the voltage value on bus 3 (Panakkukang bus) when loading 289 MW using the MFOA-ABC hybrid method was better than the two comparative methods, namely the FOA method and the ABC method with the respective voltage magnitudes amounting to 0.9037 p.u, 0.6915 p.u, and 0.6772 p.u. The voltage value of 0.9037 p.u on bus 3 using the FOA-ABC Hybrid method is considered not yet in the critical enough category, while the respective voltage values of 0.6915 p.u and 0.6772 p.u using the FOA method and the ABC method are already in a condition quite critical. The loading limit on bus 3 (Panakkukang bus) using the MFOA-ABC hybrid method, the FOA method, and the ABC method was at 289 MW, where the voltage will collapse. Meanwhile, the collapse voltage during loading was 290 MW, which was carried out on bus 3 using the MFOA-ABC hybrid method, the FOA method, and the ABC method.

Table 12. The comparison of optimization results with the generator power limit as the constraint when loading 289 MW on bus 3

Objective function	Method		
	MFOA-ABC Hybrid	FOA	ABC [14]
Total transmission power losses (MW)	26.790	134.508	142.947
Total generation fuel cost, million (IDR/hour)	459.587	506.212	509.863

Table 12 and Figure 9 show that the optimization results of the 150 kV Sulselbar electrical system test using the MFOA-ABC Hybrid method were better than the comparable methods, namely the FOA method and the ABC method. The difference in the total use of generation fuel costs for the MFOA-ABC hybrid method when compared to the FOA method was 46.625 million (IDR/hour) or there was a decrease in the use of fuel costs by 9.21%. Meanwhile, the difference in the total use of the generating fuel cost for the MFOA-ABC hybrid method when compared to the ABC method was 50.276 million (IDR/hour) or there was a decrease in the use of fuel costs by 9.86%.

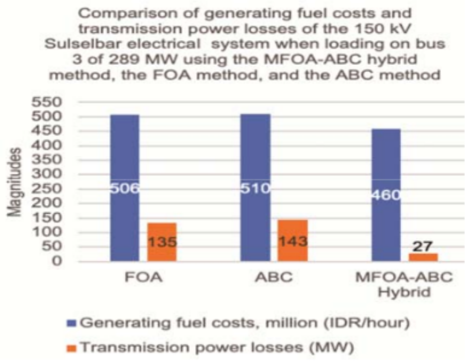

Fig.9. Comparison graph of generating fuel costs and transmission power losses when loading on bus 3 of 289 MW

The difference in total transmission power losses for the MFOA-ABC hybrid method when compared to the FOA method was 107,718 MW or there was a decrease in active power transmission line losses by 80.08%. Meanwhile, the difference in total transmission power losses for the MFOA-ABC hybrid method when compared to the ABC method was 116,157 MW or there was a decrease in transmission power losses by 81.26%.

Conclusion

The simulation results show that the MFOA-ABC hybrid optimization method proposed is effective in solving the dynamic economic dispatch problem of Sulselbar 150 kV electrical system where the value obtained is smaller than other comparable methods for the same system. The simulation results with the power limits of the generator and power balance as the constraints show that there is a decrease in transmission power losses by 35.39 to 54.35 percent and there is a decrease in generating fuel costs by 0.69 to 1.51 percent. Meanwhile, the simulation results with the power limits of the generator, power balance, and the generator ramp rate as constraints show that there is a decrease in transmission power losses by 17.99 to 20.44 percent and there is a decrease in generating fuel costs by 0.43 to 0.49 percent. The future research will consider other objective functions and constraints in the tested cases by using a new optimization technique.

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